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Effects of Dietary Glycine Betaine on Pork Quality in Different Muscle Types

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ABSTRACT : This study was conducted to determine the effects of dietary glycine betaine on pork quality in different muscle types. A total of 80 female pigs (Landrace×Yorkshire×Duroc) were randomly allotted into one of four experimental diet groups. Each group of pigs were fed a commercial diet (Control) with 0.2 g glycine betaine (T1), 0.4 g glycine betaine (T2) and 0.6 g% glycine betaine (T3)/kg for 40 days. pH of belly was significantly higher in the control than dietary glycine betaine groups at 13 days of storage, whereas pH of picnic shoulder and ham were significantly lower in control than glycine betaine groups. At 13 days of storage, redness (a*) of belly was significantly higher in control than dietary glycine betaine groups, whereas picnic shoulder and ham were significantly higher in glycine betaine groups than in the control. Water-holding capacities (WHC) of all muscle samples were significantly higher in the control than glycine betaine groups until 5 days of storage. Sarcomere length was significantly longer in the control than glycine betaine groups. The thiobarbituric acid reactive substances (TBARS) value of belly was much higher than other muscle types at 13 days of storage. In fatty acid composition, dietary glycine betaine increased the ratio of saturated fatty acids (SFA) and decreased unsaturated fatty acids (USFA) in loins. (**Key Words :** Glycine Betaine, Muscle Types, Water-holding Capacity, Sarcomere Length, Fatty Acid)

INTRODUCTION

Glycine betaine is a natural occurring product found in many plant and animal species. It is an amino acid (trimethyl-glycine) present in most organisms and is an obligatory intermediate in the catabolism of choline (Fernandez-Figares et al., 2002). Glycine betaine is actively accumulated by many mammalian cells under hypertonic conditions, and this process has widespread importance in cell-volume regulation with particularly high accumulations in the inner medulla of the mammalian kidney (Lever et al., 2004). Glycine betaine has been reported to affect some aspects of pork qualities. Matthews et al. (1998) reported that subjective color of the loin muscle in pigs fed 0.125% betaine was decreased, but subjective marbling and firmness-wetness were not affected. They also reported that addition of betaine to the diet of finishing pigs may result in improved leanness and carcass quality (Matthews et al., 2001). Fernandez-Figares et al. (2002) reported that the fat concentration in the carcass was lower in pigs consuming betaine than in controls and decreased linearly with increasing levels of dietary betaine. Some studies suggest betaine may decrease backfat thickness (Cadogan et al., 1993) and increase longissimus muscle area in pigs (Smith et al., 1995), whereas another study found that betaine has increased backfat thickness and decreased longissimus muscle area (Haydon et al., 1995). However, there is little information on the effects of dietary glycine betaine on pork quality in different muscle types. Thus, the purpose of this study was to determine the effects of dietary glycine betaine pork quality in different muscle types.

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MATERIALS AND METHODS

Animal diet and experimental protocol

A total of 80 female pigs (averaging 65 kg in weight; Landrace×Yorkshire×Duroc) were randomly allotted into one of four experimental diet groups. Pigs were allotted into four dietary groups (twenty pigs per group) on the basis of weight. Each group of pigs were fed with a commercial diet (Control) with 0.2 g glycine betaine (T1), 0.4 g glycine betaine (T2) and 0.6 g glycine betaine (T3)/kg during 40 days. Experimental diet and water were provided on an *ad libitum* basis throughout the experiment. Pigs were slaughtered at approximately 110 kg live weight and then belly, picnic shoulder and ham were fabricated according to procedures outlined by the National Association of Meat Purveyors (NAMP) guidelines (NAMP, 1997). Cold-boned samples were cut into steaks of 5cm in thickness and then

Table 1. Formula of experiment diet (%, as fed basis)

Item	Experiment diet
Ingredients	
Yellow corn	69.25
Soybean meal	14.68
Wheat bran	5.65
Rapeseed meal	3.00
Limestone	1.00
Tricalcium phosphate	0.84
Salt	0.30
Vitamin*	0.10
Mineral**	0.10
Animal fat	1.00
Molasses	4.00
Lysine	0.08
Total	100.00

* Vitamin: vit. A, 4,000 IU; vit D_3, 800 IU; vit E, 15 IU; vit B_3, 2 mg; thiamin, 8 mg; riboflavin, 2 mg; vit. B_{12}, 16 mg; pantothenicacid, 11 mg; niacin, 20 mg; biotin, 0.02 mg.

** Mineral: Cu, 130 mg; Fe, 175 mg; Zn, 100 mg; Mn, 90 mg; I, 0.3 mg; Co, 0.5 mg; Se, 0.2 mg.

individually wrap-packed after cutting. They were stored in a refrigerator at 0°C until required. pH, color, WHC, sarcomere length, TBARS and fatty acid composition were measured at 1, 5, 9 and 13 days of cold storage. 95% glycine betaine was purchased from commercial bio-chemical company (CTC Bio, Korea, Seoul).

pH analysis

pH was measured using a digital pH meter (Model 420A, Orion, MA, USA). Five grams of meat was cut into small pieces to which 45 ml of distilled water was added and slurry was made using a blender and the pH was recorded.

Meat color analysis

Meat color (CIE a*) was measured by using a Minolta Chromameter (Minolta CR 301; Tokyo, Japan). Five random readings were made from the surface of samples.

Water holding capacity (WHC) analysis

Five grams of meat were weighed into centrifugation tubes and thereafter centrifuged at 5°C at low speed (1,000 g for 15 min). The WHC was determined as liquid loss and expressed as percentage of weight of liquid release. WHC % = (before centrifuge weight-after centrifuge weight)/(before centrifuge weight)×100.

Sarcomere length analysis

Muscles were fixed by 4% formaldehyde, 15% absolute alcohol and 1.5 g thymol for 2 weeks. Fibre bundles taken out of the muscle were exposed to a 17.5% KOH solution for 4 h after which they were stored in a 50% glycerol solution for 2-4 days to soften connective tissue. From every region five isolated fibres were teased out for their whole length. From each cube, sarcomere length of eight fiber samples was determined (24 total measurements per observation) by helium neon laser diffraction (05-LHR-021, Melles Griot, Carlesbad, CA, USA) as described by Cross et al. (1981).

TBARS analysis

Five grams of meat were weighed into a 50-ml test tube and homogenized with 15 ml of deionized distilled water using the Polytron homogenizer for 10 s at the highest speed. One ml of meat homogenate was transferred to a disposable test tube (3×100 mm), and butylated hydroxyanisole (50 μl, 10%) and thiobarbituric acid/ trichloroacetic acid (TBA/TCA) (2 ml) were added. The mixture was vortexed and then incubated in a boiling water bath for 15 min to develop color. The sample was cooled in cold water for 10 min, vortexed again, and centrifuged for 15 min at 2,000×g. The absorbance of the resulting supernatant solution was determined at 531 nm against a blank containing 1 ml of DDW and 2 ml of TBA/TCA solution. The amounts of TBARS were expressed as milligrams of malondialdehyde per kilogram of meat.

Fatty acid analysis

Lipids were extracted with chloroform and methanol as described by Folch et al. (1957). Five grams of meat were combined with 50 ml of Folch solution (chloroform:methanol, 2:1, vol/vol) and 50 μl of BHA (butylhydroxyanisole, 50 ml, 10%) and homogenized with a Polytron homogenizer (IKA Labortechnik T25-B, Selangor, Malaysia) for 10 s. The homogenate was filtered with Whatman No. 1 filter paper. The residue and filter paper were blended with 50 ml of the Folch solution and refiltered. Distilled water (25 ml) was added to the filtered solution and centrifuged at 500 rpm for 10 min. The upper layer (methanol and water layer) was removed using an aspirator, and the bottom layer (chloroform containing lipid extract) was passed through anhydrous sodium sulfate (Na_2SO_4). The Na_2SO_4 was rinsed with 30 ml of chloroform. The extracts were concentrated using an evaporator (Zymark turbovap 500, Hopkinton, MA, USA) at 40°C under nitrogen and stored at -40°C until required for analysis. For lipid hydrolysis, an aliquot of lipid extract (30 mg) and 3 ml of 4% H_2SO_4 in methanol were combined in a screw-capped test tube. The test tube was placed in boiling water (100°C) for 20 min and subsequently cooled at room temperature. The resulting free fatty acids were methylated with 1 ml of 14% boron trifluoride in methanol at room temperature for 30 min. Water (1 ml) and hexane (5 ml) were added. Samples were vortexed and centrifuged at 500×g for 10 min. The upper organic solvent layer was used

Table 2. Effect of ditary glycine betaine on pH in different muscle types

Treatments		Storage (days)			
		1	5	9	13
Belly	C	5.71±0.18^{BC}	5.76±0.13^{B}	5.74±0.09^{BC}	5.92±0.04^{A}
	T1	5.76±0.09^{BC}	5.80±0.11^{AB}	5.80±0.07^{B}	5.77±0.06^{C}
	T2	5.80±0.12^{B}	5.83±0.16^{A}	5.83±0.04^{B}	5.86±0.07^{AB}
	T3	5.76±0.10^{BC}	5.75±0.05^{B}	5.83±0.06^{B}	5.84±0.05^{B}
Picnic shoulder	C	5.80±0.06^{B}	5.74±0.14^{C}	5.78±0.14^{BC}	5.76±0.09^{C}
	T1	5.71±0.09^{BCb}	5.85±0.13^{Aab}	5.99±0.13^{Aa}	5.85±0.05^{ABab}
	T2	5.66±0.06^{C}	5.78±0.21^{AB}	5.99±0.13^{A}	5.92±0.05^{A}
	T3	5.98±0.15^{A}	5.79±0.11^{AB}	5.82±0.18^{BC}	5.84±0.03^{AB}
Ham	C	5.64±0.06^{C}	5.70±0.15^{C}	5.69±0.13^{C}	5.81±0.09^{B}
	T1	5.60±0.01^{Cb}	5.69±0.04^{Cab}	5.73±0.18^{BCab}	5.90±0.10^{Aa}
	T2	5.73±0.17^{BC}	5.75±0.19^{B}	5.72±0.15^{BC}	5.96±0.09^{A}
	T3	5.83±0.19^{B}	5.82±0.11^{A}	5.76±0.17^{BC}	5.96±0.07^{A}

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[A, B, C] Means in the same column with different letters are different ($p<0.05$). [a, b] Means in the same row with different letters are different ($p<0.05$).

Table 3. Effect of dietary glycine betaine on redness (a*) in different muscle types

Treatments[1]		Storage (days)			
		1	5	9	13
Belly	C	7.36±1.48^{Eb}	8.10±1.78^{Db}	8.29±1.23^{Eb}	13.19±2.80^{Ca}
	T1	6.70±1.00^{Fb}	7.46±0.93^{Db}	8.13±0.97^{Eb}	17.76±2.59^{Aa}
	T2	8.25±1.78^{Db}	7.33±0.69^{Db}	7.76±1.60^{Fb}	15.56±2.28^{Ba}
	T3	7.02±0.67^{Eb}	7.45±1.09^{Db}	7.77±0.47^{Fb}	15.17±1.64^{Ba}
Picnic shoulder	C	13.89±1.07^{Bb}	18.04±2.05^{Aa}	16.54±2.09^{Aa}	12.39±2.26^{Db}
	T1	15.59±1.74^{A}	17.15±2.61^{AB}	16.38±2.31^{AB}	15.65±1.83^{B}
	T2	14.92±0.67^{AB}	17.48±2.96^{AB}	15.62±2.17^{AB}	14.84±2.43^{BC}
	T3	15.15±1.15^{ABb}	17.14±2.00^{ABa}	17.08±2.45^{Aa}	13.74±1.55^{Cb}
Ham	C	13.41±1.80^{BCa}	13.61±2.38^{Ca}	11.23±1.25^{Cab}	10.02±2.62^{Eb}
	T1	12.10±1.13^{C}	13.33±2.89^{C}	14.22±1.41^{B}	13.16±2.54^{C}
	T2	10.96±1.40^{Cb}	15.94±1.09^{Ba}	10.60±1.08^{Db}	10.54±2.54^{Eb}
	T3	10.03±0.83^{CDb}	12.92±2.85^{Cab}	12.92±2.05^{Cab}	14.59±2.82^{BCa}

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[A, B, C, D, E, F] Means in the same column with different letters are different ($p<0.05$). [a, b] Means in the same row with different letters are different ($p<0.05$).

to determine fatty acids composition. Fatty acid methyl esters were analyzed on a gas chromatograph (Shimadzu GC-14A; Tokyo, Japan) equipped with an on-column injector port and flame-ionization detector. A Silar capillary column (30 m×0.32 mm×0.25 μm; Shimadzu, Japan) was used for the separation of the fatty acid methyl esters. The gas chromatography oven temperature was 140°C, and increased at a rate of 2°C/min to a final temperature of 230°C. The temperatures of injector port and detector temperatures were set at 240°C and 250°C, respectively. Fatty acid methyl ester (1 μl) was injected onto the split injection port (100:1 split ratio). The flow rate for He carrier gas was 50 ml/min. Each fatty acid was detected by the standards' retention time.

Statistical analysis

The effects of dietary glycine betaine on pork quality in different muscle types were analyzed using SAS software (SAS Inst. Inc., Cary, NC) by the generalized linear model procedure; the Student-Newman-Keuls' multiple range test was used to compare the differences among means. Significance was defined at $p<0.05$.

RESULTS AND DISCUSSION

pH

As shown in Table 2, pH of belly was significantly higher in control group than glycine betaine groups at 13 days of storage, whereas pH of picnic shoulder and ham were significantly lower in control group than glycine betaine groups at 13 days of storage. Especially, pH of ham was significantly increased by dietary glycine betaine in all of storage periods although variation was large around the mean. In this study, we assumed that dietary glycine betaine influenced pH during storage. In generally, the pH is closely related to color, tenderness and WHC in meat during storage. Honikel (1987) reported that pH has a profound effect on the water holding capacity, and meat pH significantly affected L*, a* and b* (Swan and Boles, 2002).

Table 4. Effect of dietary glycine betaine on water holding capacity in different muscle types (%)

Treatments[1]		Storage (days)			
		1	5	9	13
		%			
Belly	C	47.02±4.32^{Cc}	67.67±2.79^{Aa}	59.01±3.98^{b}	48.29±4.15^{c}
	T1	40.94±4.81^{Eb}	40.00±4.49^{Fb}	56.31±3.53^{a}	49.41±5.41^{a}
	T2	41.23±5.34^{Db}	53.24±4.95^{Ca}	56.56±4.01^{a}	48.51±3.66^{ab}
	T3	56.23±5.18^{Aa}	48.41±3.07^{Db}	56.66±2.22^{a}	50.51±2.62^{b}
Picnic shoulder	C	52.53±3.29^{Bb}	56.95±4.02^{Ba}	60.87±4.59^{a}	50.80±3.40^{b}
	T1	49.81±2.57^{BCb}	42.73±2.68^{Ec}	59.58±3.70^{a}	51.20±4.57^{b}
	T2	41.64±3.35^{Dc}	40.64±3.47^{Fd}	61.09±4.95^{a}	50.98±3.40^{ab}
	T3	50.46±1.48^{BCb}	47.41±1.32^{Db}	60.46±2.02^{a}	48.02±2.57^{b}
Ham	C	50.65±2.14^{BCab}	46.27±4.66^{Db}	58.63±4.04^{a}	48.29±3.73^{b}
	T1	40.72±2.67^{Ec}	42.63±3.04^{Fc}	57.58±2.87^{a}	50.64±4.39^{b}
	T2	46.98±3.33^{Cb}	40.96±3.11^{Ec}	59.92±4.84^{a}	48.74±4.80^{b}
	T3	49.07±1.23^{BCb}	42.12±4.72^{Ec}	59.32±3.12^{a}	49.99±2.36^{b}

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[A, B, C, D, E, F] Means in the same column with different letters are different ($p<0.05$). [a, b, c] Means in the same row with different letters are different ($p<0.05$).

Table 5. Effect of dietary glycine betaine on sarcomere length in different muscle types

Treatments[1]		Storage (days)			
		1	5	9	13
		μm			
Belly	C	1.63±0.07^{Ac}	1.81±0.14^{Bb}	1.90±0.15^{Bb}	2.11±0.30^{Aa}
	T1	1.10±0.15^{Dd}	1.79±0.16^{BCc}	1.98±0.10^{Ab}	2.18±0.20^{Aa}
	T2	1.52±0.21^{Bc}	1.66±0.18^{Cc}	1.89±0.21^{Bb}	2.21±0.30^{Aa}
	T3	1.12±0.09^{Ec}	1.21±0.07^{Gbc}	1.26±0.06^{Gb}	1.43±0.26^{Ca}
Picnic shoulder	C	1.55±0.12^{Bc}	1.64±0.15^{CDc}	1.82±0.13^{Cb}	1.95±0.15^{Aa}
	T1	1.50±0.09^{BCc}	1.60±0.06^{Db}	1.76±0.14^{Da}	1.81±0.12^{ABa}
	T2	1.67±0.26^{Ab}	1.86±0.24^{Aab}	1.97±0.30^{Aa}	2.01±0.30^{Aa}
	T3	1.41±0.13^{Cc}	1.53±0.06^{Eb}	1.63±0.08^{Ea}	1.65±0.10^{Ba}
Ham	C	1.48±1.33^{BCd}	1.62±0.07^{Dc}	1.88±0.11^{Bb}	2.02±0.26^{Aa}
	T1	1.49±0.11^{BCc}	1.66±0.10^{Cb}	1.74±0.14^{Db}	1.91±0.39^{Aa}
	T2	1.53±0.23^{Bc}	1.66±0.19^{Cbc}	1.83±0.10^{Cab}	2.02±0.59^{Aa}
	T3	1.36±0.14^{Dc}	1.42±0.12^{Fc}	1.52±0.13^{Fb}	1.66±0.10^{Ba}

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[2] MA: Malondialdyhyde.
[A, B, C, D] Means in the same column with different letters are different ($p<0.05$). [a, b, c, d] Means in the same row with different letters are different ($p<0.05$).

Thus, the changes of pH by dietary glycine betaine might be influenced with meat qualities.

Meat color

At the 13 days of storage, redness (a*) of belly and picnic shoulder were significantly higher in dietary glycine betaine groups than control group, whereas 0.4 g dietary glycine betaine group (T2) was no significantly difference compared with control group in ham. However, some studies showed a negative effect of glycine betaine on meat color. Øverland et al. (1999) reported that subjective color was paler in pigs fed betaine. Matthews et al. (2001) did not observe any effects on color of pigs fed betaine in the loin muscle or biceps femoris muscle. Meat pH is closely related to the meat color, and high pH meat has a more compact muscle structure, which limits oxygen diffusion and light absorption (Swan and Boles, 2002). The high pH should increase darkness because high pH has been associated with reduced oxygenation rate of myoglobin to the bright red oxymyoglobin (Swan and Boles, 2002). However, redness also increased by pH increase until some level of pH. In this study, redness (a*) results were similar to the pH results in all samples. Thus, dietary glycine betaine can improve the redness by pH increase. Another possible mechanism for redness increasing is the decrease lipid and increase lean mass by dietary glycine betaine. In generally, fat in meat has been closely associated with lightness (L*) caused by the redness or yellowness decrease. Our previous result showed that lipid amount was decreased and lightness (L*) was increased by dietary glycine betaine (data are not shown). It is probably the main reason for redness (a*) increasing.

Table 6. Effect of ditary glycine betaine on lipid oxidation in different muscle types

Treatments[1]		Storage (days)			
		1	5	9	13
		MA[2] (mg/kg)			
Belly	C	0.20±0.05^{d}	0.25±0.10^{c}	0.30±0.01^{Ab}	0.34±0.04^{Aa}
	T1	0.19±0.05^{d}	0.25±0.03^{c}	0.30±0.02^{Ab}	0.33±0.07^{Aa}
	T2	0.20±0.01^{d}	0.26±0.03^{c}	0.30±0.01^{Aab}	0.32±0.03^{Aa}
	T3	0.21±0.05^{d}	0.25±0.05^{c}	0.28±0.03^{ABb}	0.32±0.03^{Aa}
Picnic shoulder	C	0.20±0.05^{c}	0.23±0.02^{b}	0.23±0.03^{Bb}	0.25±0.01^{Ca}
	T1	0.21±0.02^{b}	0.23±0.01^{b}	0.23±0.02^{Bb}	0.25±0.07^{Ca}
	T2	0.20±0.02^{b}	0.22±0.01^{ab}	0.23±0.02^{Bab}	0.25±0.03^{Ca}
	T3	0.20±0.03^{b}	0.22±0.03^{ab}	0.22±0.02^{Bab}	0.25±0.01^{Ca}
Ham	C	0.21±0.05^{c}	0.21±0.17^{c}	0.24±0.01^{Bb}	0.29±0.05^{ABa}
	T1	0.20±0.01^{c}	0.22±0.02^{b}	0.23±0.01^{Bb}	0.28±0.03^{ABa}
	T2	0.20±0.03^{d}	0.22±0.02^{c}	0.24±0.01^{Bb}	0.27±0.01^{Ba}
	T3	0.20±0.05^{c}	0.20±0.03^{c}	0.24±0.03^{Bb}	0.26±0.04^{Ba}

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[2] MA: Malondialdyhyde.
[A, B] Means in the same column with different letters are different ($p<0.05$). [a, b, c, d] Means in the same row with different letters are different ($p<0.05$).

Table 7. Effect of dietary glycine betaine on fatty acid composition in different muscle types

Treatments[1]		Fatty acid (%)							
		Myristic acid	Palmitic acid	Palmitoleic acid	Stearic acid	Oleic acid	Linoleic acid	Archidonic acid	SFA/ USFA[2]
Belly	C	1.55±0.05^{AB}	18.89±0.10^{B}	2.13±0.02	12.76±0.11^{D}	45.65±0.15^{A}	16.69±0.15^{AB}	2.33±0.09^{D}	33.20/66.80
	T1	1.42±0.04^{AB}	18.98±0.04^{B}	2.27±0.07	14.31±0.03^{B}	42.63±0.12^{D}	17.27±0.20^{A}	3.17±0.10^{C}	34.71/65.34
	T2	1.61±0.05^{AB}	18.44±0.15^{C}	2.54±0.03	15.01±0.09^{A}	42.09±0.19^{D}	17.18±0.07^{A}	3.12±0.02^{C}	35.06/64.92
	T3	1.30±0.07^{AB}	18.31±0.05^{C}	2.45±0.15	15.71±0.08^{A}	45.28±0.23^{A}	14.72±0.19^{C}	2.24±0.01^{D}	35.32/64.69
Picnic shoulder	C	1.37±0.03^{AB}	18.11±0.21^{C}	2.21±0.09	12.73±0.06^{D}	43.73±0.11^{C}	18.34±0.23^{A}	3.52±0.15^{BC}	32.21/67.80
	T1	1.51±0.06^{AB}	19.84±0.20^{A}	2.25±0.17	14.26±0.10^{B}	45.25±0.20^{A}	12.61±0.09^{D}	4.28±0.07^{A}	35.61/64.39
	T2	1.54±0.08^{AB}	19.32±0.04^{AB}	3.51±0.20	13.16±0.05^{C}	43.89±0.12^{C}	15.07±0.33^{B}	3.51±0.11^{BC}	34.02/65.98
	T3	1.27±0.09^{B}	18.55±0.19^{C}	2.39±0.30	14.13±0.10^{B}	44.22±0.03^{B}	16.09±0.26^{AB}	3.48±0.18^{BC}	33.95/66.18
Ham	C	1.78±0.03^{A}	18.88±0.11^{B}	2.30±0.02	11.03±0.13^{E}	45.70±0.27^{A}	15.53±0.15^{B}	4.08±0.03^{A}	31.69/67.61
	T1	1.52±0.02^{AB}	19.50±0.04^{A}	2.27±0.05	13.46±0.05^{C}	45.83±0.13^{A}	14.14±0.09^{C}	3.28±0.16^{C}	34.48/65.52
	T2	1.32±0.06^{AB}	19.92±0.15^{A}	3.10±0.14	12.35±0.02^{D}	45.34±0.19^{A}	14.33±0.10^{C}	3.64±0.05^{B}	33.59/66.41
	T3	1.20±0.08^{B}	19.44±0.07^{A}	2.38±0.06	13.71±0.06^{C}	43.53±0.20^{C}	15.85±0.29^{B}	3.89±0.16^{B}	34.35/65.65

[1] C: commercial diet, T1: containing 0.2 g glycine betaine, T2: containing 0.4 g glycine betaine, T3: containing 0.6 g glycine betaine/kg diet.
[2] SFA/USFA: saturated fatty acid/unsaturated fatty acid.
[A, B, C, D, E] Means in the same column with different letters are different ($p<0.05$).

Water-holding capacity

WHC was significantly increased with storage periods until 9 days of storage after a while WHC was decreased in all dietary groups. WHC of all muscle samples were significantly higher in control group than glycine betaine groups until 5 days of storage. However, WHC was no significantly different in all dietary groups at 9 and 13 days of storage. Meat industry, low WHC implies increased economical losses, and consequently there is a strong interest in optimizing this parameter (Schafer et al., 2002). Schafer et al. (2002) reported that physical factors of importance to water-holding are mainly thought to be temperature post mortem, shrinkage of the myofilament lattice post mortem due to pH fall and actomyosin cross bridges, myosin denaturation, structural changes at the fibre and fibre bundle level that lead to an increase of the extra-cellular space. In this study, WHC decreased by dietary glycine betaine. This may be due to increased protein contents and decreased fat contents. Fernandez-Figares et al. (2002) and Yu et al. (2004) reported that the rate of protein deposition in the carcass tended to be linearly related to the dietary betaine content, and lean gain efficiency also was numerically improved by dietary betaine. Saunderson and Mackinlay (1990) and Feng et al. (2006) reported that betaine is effective in reducing body fat and increasing the protein in chicken and barrows. Lawrence et al. (1995) and Cardogan et al. (1993) also reported that dietary betaine was associated with decreased backfat thickness, although growth performance and carcass traits were not affected. Previous our study also shown to be dietary glycine betaine was increased protein content and decreased fat content (data are not shown). In general, water in meat is placed in

protein portion, thus, meat containing high protein may has increased WHC compared with meat containing high fat when same condition of handling or storage. This result would not be beneficial effect from the point of view of economical losses.

Sarcomere length

Sarcomere length was significantly increased with storage periods in all dietary groups and all muscle types. Sarcomere length was significantly longer in control group than glycine betaine groups. Especially, sarcomere length of all muscle types was significantly shorter in 0.6 g dietary glycine betaine group (T3) at end of storage. Sarcomere length which serves as an index for evaluating tenderness is proportional to the tenderization process and is influenced by the degree of tension on the skeletal muscles by their skeletal attachment (Biswas et al., 2007). In this study, we found that sarcomere length was decreased by dietary glycine betaine in all muscle types. This may influence meat tenderness or WHC. Wheeler and Koohmaraie (1999) also reported that sarcomere length can influence meat tenderness, due to the extent of proteolytic degradation of key myofibrillar and cytoskeletal protein. Thus, dietary glycine betaine should decrease tenderness and WHC in the present study. However, more research is needed to determine the effect of sarcomere length on meat qualities in different muscle types of pork.

TBARS value

TBARS value was significantly increased with storage periods in all dietary groups and all muscle types. The TBARS value of belly was much higher than other muscle types at 13 days of storage. In generally, lipid oxidation is a leading cause of quality deterioration in meat and meat products. Because the oxidation greatly reduces consumer acceptability because of associated rancid flavors (Cross et al., 1987). However, dietary glycine betaine had no significant influence on TBARS value in all muscle samples. This indicates that dietary glycine betaine may not influence lipid oxidation regardless of muscle types.

Fatty acids composition

Dietary glycine betaine increased the ratio of SFA and decreased USFA in all samples. The proportion of myristic acid and linoleic acid were decreased by dietary glycine betaine, whereas those of stearic acid were increased by dietary glycine betaine. These changes are main reason for increased SFA and decreased USFA. This result agreed with Fernandez et al. (1998) who reported that dietary glycine betaine significantly reduced USFA and increased SFA. Usually, the structure of SFA is more stable than USFA, thus, increase of SFA by dietary glycine betaine can increase meat tenderness. There are indications that glycine betaine may play a role in fatty acid metabolism.

CONCLUSION

As a result of this study, we found that pH and redness (a*) were increased by dietary glycine betaine, whereas WHC and Sarcomere length were decreased. And also dietary glycine betaine influenced the fatty acid composition as increased SFA and decreased USFA. Thus, we assume that dietary glycine betaine may improve leanness and redness (a*), however, other meat qualities such as tenderness or WHC may be negative. It would be indicated that dietary glycine betaine is not much useful from the point of view of physical qualities of pork. However, several studies reported positive effects on meat quality by dietary glycine betaine, thus, more studies are needed to determine the effect of dietary glycine betaine on meat quality.

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